BY SAM GOLDWASSER
SERVICE EDITOR

Testing Semiconductors

THIS MONTH WE WILL TAKE A BREAK FROM HEAVY TROUBLESHOOTING TO GO OVER SOME OF THE BASIC TECHNIQUES FOR TESTING OF COMMON SEMICONDUCTORS. WHILE FANCY TRANSISTOR TESTERS AND CURVE TRACERS HAVE THEIR place, when you just want to know if your horizontal output transistor is toast or not they can be more trouble than they are worth. Most (though not all) failures of diodes, transistors, SCRs, and so forth, result in unambiguous changes to the device parameters that can be found with very simple tests typically using a DMM or VOM, a power supply, and a few resistors.

In most cases, these simple tests will identify bad silicon transistors. Gain, frequency response, etc., are not addressed here. While the tests can be applied to germanium devices, these are more likely to change characteristics, it would seem, without totally failing.

Safety Considerations

None of the tests described here require probing live circuits. However, before touching, probing, or unsoldering any component, make sure the equipment is unplugged and any large capacitors have been safely discharged. Not only can coming in contact with a live circuit or charged capacitor ruin your day, but your test equipment could be damaged or destroyed as well.

VOMs and DMMs

Analog and digital meters behave quite differently when testing nonlinear devices like diodes and transistors. For example, it is important to remember that an analog VOM on the lowest resistance range could put out too much current for smaller devices, possibly damaging them. Ironically, this is more likely with better meters like the Simpson 260, which can test to lower ohms (×1 scale). Use the next higher resistance range in this case or a DMM, as those never drive the device under test with significant current. However, this can result in false readings as the current may be too low to adequately bias the junctions of some power devices or devices with built-in resistors.

Testing Diode Junctions with a Multimeter

On the (analog) VOM, use the low ohms scale. A regular signal diode or rectifier should read a low resistance (typically ⅔ scale or a couple hundred ohms) in the forward direction and infinite (nearly) resistance in the reverse direction. It should not read near 0 ohms (shorted) or open in both directions. A germanium diode will result in a higher scale reading (lower resistance) due to its lower voltage drop.

For the VOM, you are measuring the resistance at a particular (low current) operating point—this is not the actual resistance that you will see in a power rectifier circuit, for example.

On a (digital) DMM, there will usually be a diode-test mode. Using this, a silicon diode should read between 0.5 to 0.8 V in the forward direction and open in reverse. For a germanium diode, it will be lower, perhaps 0.2 to 0.4 V or so in the forward direction. Using the normal resistance ranges—any of them—will usually show open for any semiconductor junction since the meter does not apply enough voltage to reach the value of the forward drop. Note, however, that a defective diode may indeed indicate a resistance lower than infinity especially on the highest ohms range. So, any reading of this sort would be an indication of a bad device but the opposite is not guaranteed.

Note: For a VOM, the polarity of the probes is often reversed from what you would expect from the color coding—the red lead is negative with respect to the black one. DMMs usually have the polarity as you would expect it. Confirm this using a known diode as a reference. Also, "calibrate" your meter with both silicon and germanium semiconductors so you will know what to expect with an unknown device.

Transistor Testing Methodology

As with diode junctions, most digital meters show infinite resistance for all six

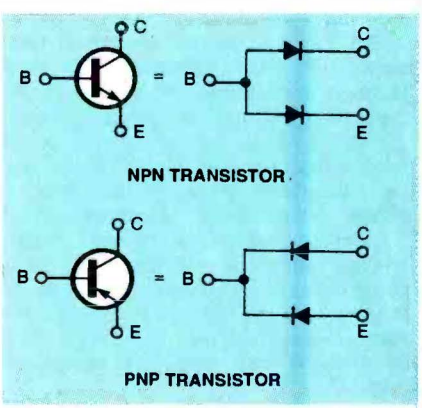

FIG. 1—A BIPOLAR TRANSISTOR can be modeled using diodes.

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combinations of junction measurements since their effective resistance-test voltage is less than a diode junction drop (if you accidentally get your skin involved it will show something between 200K and 2M ohms). The best way to test transistors with a DMM is to make use of the "diode-test" function, which will be described after we talk about testing with an analog meter. Regardless of whether you test with an analog or digital meter, if you read a short circuit (0 ohms or voltage drop of 0) or the transistor fails any of the readings, it is bad and must be replaced. This discussion is for **out-of-circuit** transistors **only**.

One exception to this occurs with some power transistors, which have built-in diodes (damper diodes reverse connected across the C-E junction) and resistors (B-E, around 50 ohms) that will confuse these readings. If you are testing a transistor of this type—horizontal output transistors are the most common example—you will need to compare with a known good transistor or check the specifications to be sure. There are some other cases as well. So, if you get readings that do not make sense, try to confirm with a known good transistors of the same type or with a spec sheet.

Before testing an unknown device, it is best to confirm and label lead polarity (of voltage provided in resistance or diode test mode) of your meter whether it be an analog VOM or digital DMM using a known good diode (*e.g.*, 1N4007 rectifier or 1N4148 signal diode) as discussed below. This will also show you what to expect for a reading of a forward-biased junction. If you expect any germanium devices, you should do this with a germanium diode as well (*e.g.*, 1N34).

Note that this discussion assumes that a transistor can be tested for shorts, opens, or leakage, as though it is just a pair of connected diodes. The equivalent diode circuits for NPN and PNP bipolar transistors are shown in Fig. 1.

Obviously, simple diodes can be tested as well using this technique. However, LEDs (their forward drop is too high for most meters) and Zeners (their reverse breakdown—Zener voltage—is too large for most meters) cannot be fully tested in this manner. Those and other types of devices are discussed later in this article.

Testing With an Analog VOM

For NPN transistors, lead "A" is black and lead "B" is red; for PNP transistors, lead "A" is red and lead "B" is black (Note: This is the standard polarity for resistance, but many multimeters have the colors reversed since this makes the internal circuitry easier to design; if the readings don't jive this way, switch the leads and try it again). Start with lead "A" of your multimeter on the base and lead "B" on the emitter. You should get a reasonable low resistance reading. Depending on scale, this could be anywhere from 100 ohms to several thousand ohms. The actual value is not critical as long as it is similar to the reading you got with your "known good diode test" above. All silicon devices will produce somewhat similar readings and all germanium devices will result in similar but lower resistance readings.

Now move lead "B" to the collector. You should get nearly the same reading. Now try the other four combinations, and you should get a reading of infinite ohms (open circuit). If any of those resistances is wrong, replace the transistor. Only two of the six possible combinations should show a low resistance; none of the resistances should be near 0 ohms (shorted).

As noted above, some types of devices include built-in diodes or resistors, which can confuse these measurements.

Testing With a Digital DMM

Set your meter to the diode test. Connect the red meter lead to the base of the transistor. Connect the black meter lead to the emitter. A good NPN transistor will read a junction drop voltage of between 0.45v and 0.9v. A good PNP transistor will read open. Leave the red meter lead on the base and move the black lead to the collector. The reading should be the same as the previous test. Reverse the meter leads in your hands and repeat the test. This time, connect the black meter lead to the base of the transistor. Connect the red meter lead to the emitter. A good PNP transistor will read a junction drop voltage of between 0.45 V and 0.9 V. A good NPN transistor will read open. Leave the black meter lead on the base and move the red lead to the collector. The reading should be the same as the previous test. Place one meter lead on the collector, the other on the emitter. The meter should read open. Reverse your meter leads. The meter should read open. This is the same for both NPN and PNP transistors.

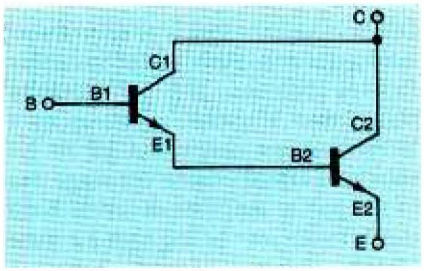

FIG. 2—A DARLINGTON TRANSISTOR is two transistors within a single package and is connected as shown here.

Again, as noted, some transistors will have built-in diodes or resistors which can confuse these readings.

Testing Power Transistors

Power transistors without internal damper diodes test just about like small signal transistors using the dual diode model, high in one direction, either B-E or B-C. If there is a built-in damper diode, it is across C-E junction and is back biased under normal operating conditions. Therefore, a reading between C-E will also test low in one direction and B-C will show a double diode drop in the reverse direction.

Also, there is often a low value resistor—about 50 ohms—between B-E when there is a built-in damper. This will show up as a nearly zero-volt junction drop on the diode test scale of a DMM, but such a reading does not indicate a bad part. Use the resistance scale to confirm.

Testing Darlington Transistors

A Darlington transistor—see Fig. 2—is a special type of configuration usually consisting of 2 transistors fabricated on the same chip or at least mounted in the same package. Discrete implementations as well as Darlingtons with more than 2 transistors are also possible.

In many ways, a Darlington configuration behaves like a single transistor where:

- the current gains of the individual transistors it is composed of are multiplied together and,
- the B-E voltage drops of the individual transistors it is composed of are added together.

Darlingtons are used where drive is limited and the high gain—typically over 1000—is needed. Frequency response is not usually that great, however.

Testing a Darlington with a VOM or

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DMM is basically similar to that of normal bipolar transistors, except that in the forward direction, B-E will measure higher than a normal transistor on a VOM (but not open), and 1.2 to 1.4 volts on a DMM's diode-test range due to the pair of junctions in series. Note that 1.2 volts may be too high for some DMMs, and thus a good Darlington may test open—confirm that the open circuit reading on your DMM is higher than 1.4 volts or check with a known good Darlington.

Testing Digital or Bias Resistor Transistors

Occasionally you may find a transistor that includes an internal bias resistor network attached to the base and emitter so that it can be driven directly from a digital (e.g., TTL) source; see Fig. 3. These may be used in consumer elec-

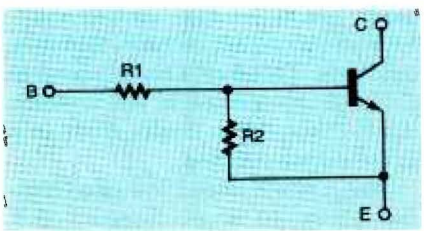

FIG. 3—AN INTERNAL BIAS RESISTOR is sometimes present to allow a transistor to be driven directly from a TTL-level signal.

tronics equipment where space is critical, or for no good reason other than to make it difficult to locate a suitable replacement device!

The addition of R1 makes testing with a multimeter other than for shorts more difficult. With a VOM, you should see a difference in the B-E and B-C junctions in the forward and reverse directions. However, a DMM will probably read open across all pairs of terminals.

Testing Zener Diodes

The following applies to both testing of Zeners for failure and determining the ratings of an unknown device:

With a VOM, a good Zener diode should read like a normal diode in the forward direction and open in the reverse direction unless the VOM applies more than the Zener voltage for the device. A DMM on its diode test range may read the actual Zener voltage if it is very low (*e.g.*, a couple of volts) but will read open otherwise. The most common failure would be for the device to short—read 0.0 ohms in both direc-

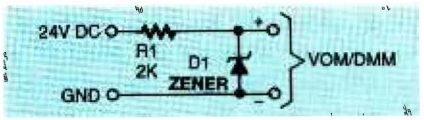

FIG. 4—USE THIS CIRCUIT to test Zener diodes.

tions. Then, it is definitely dead!

Some Zeners are marked with a JEDEC (1N) part number, others with a couple of colored bands (*e.g.*, for 18 volts the bands would be brown and gray), or a house number or house color code.

You can easily test a Zener and identify its voltage rating with a DC power supply, resistor, and multimeter. You will need a power supply (a DC wall adapter or AC wall adapter with a rectifier and filter capacitor is fine) greater than the highest Zener voltage you want to test. Select a resistor that will limit current to a few mA. For example, for Zeners up to about 20 V, you can use the circuit in Fig. 4. This same approach applies to other devices that exhibit a similar behavior, such as the B-E junction of a bipolar transistor.

Testing Unijunction and Programmable Unijunction Transistors

Unijunction Transistors (UJTs) and Programmable Unijunction Transistors (PUTs) are used in similar sorts of circuits, though the UJT is all but extinct. They both exhibit a negative resistance characteristic and can be used easily in low to medium frequency free-running relaxation oscillators and other trigger type circuits.

The UJT (see Fig. 5) goes into heavy conduction from E to B1 when E becomes more positive than a critical trigger voltage, $V_T = n \times V_{BB} + 0.6$. (Note, n, the "intrinsic standoff voltage," is typically about 0.6.) It continues to conduct until the emitter current drops

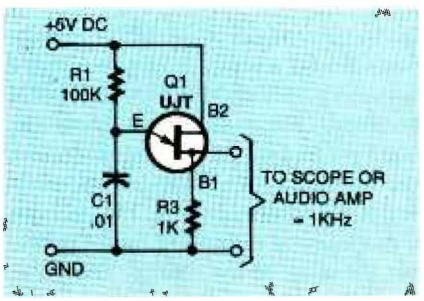

FIG. 5—UNIJUNCTION TRANSISTORS are not that common these days, but if you come across one this circuit can be used to test it.

below some minimum 'valley current' value. (Sounds sort of like a thyristor, right?)

The PUT (see Fig. 6) is even more like a thyristor in that the triggering takes place when the G terminal becomes more positive than the A (probably plus a diode drop, 0.6 V) so that the threshold voltage can now be set with a voltage divider feeding the anode.

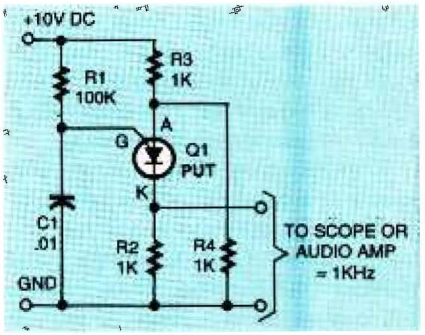

FIG. 6—A CIRCUIT FOR TESTING programmable unijunction transistors (PUTs) is shown here.

Then, current flows from the G to the K terminal. Note that its leads are even labeled like an SCR, but it behaves sort of backwards!

For an initial test, check between B1 and B2 (UJT) or A and K (PUT) with an ohmmeter. The resistance should be the same in both directions and typically a few thousand ohms or more. A short or wildly different readings would indicate a bad device. This doesn't prove that the device is good—only that it hasn't blown up. A more complete test requires a simple circuit and some means of detecting an audio output signal. For the UJT, use the set up in Fig. 5; for the PUT, an additional voltage divider (R3 and R4) is needed to set the threshold as shown in Fig. 6.

Testing SCRs and Triacs

Next, let's deal with testing various types of thyristors. For SCRs, the gate to cathode should test like a diode (which it is) on a multimeter. The anode to cathode and gate to anode junctions should read open. For Triacs, the gate to main terminal 2 (MT2) should test like a diode junction in both directions. MT1 to MT2 and the gate to MT1 junctions should read open. For diacs and sidacs, there is no gate terminal—resistance should be infinite in both directions.

Note: Some thyristors will have a low G-K/MT2 resistance but it should not read as a short.

The real test is quite simple but will

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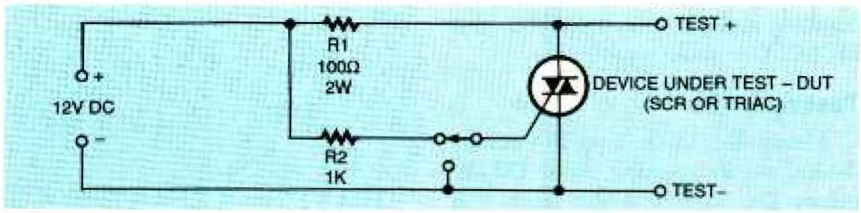

FIG. 7—IN THIS SCR/TRIAC test circuit, R1 limits current to the device under test, and R2 limits current to its gate.

require a low voltage DC power supply and two resistors. For Triacs, a negative output from the supply is also desirable to test the triggering when the gate is negative.

To test SCRs or Triacs, use the circuit shown in Fig. 7. There, R1 is used to limit current through the device and R2 is used to limit current to the gate. The 12-VDC supply should be capable of currents to at least 200 mA. Note that R1 calls for a unit with a 2-watt rating; a /-watt unit should be sufficient for R2. Those ratings should work for testing most small to medium power devices. Check the "minimum gate current" and "holding current" specs to be sure. For larger devices, R1 and/or R2 might need to be smaller.

Here's the procedure:

1. Connect the supply as shown.
2. Trigger the gate from the positive of the supply through the current limiting resistor (R2) and see that the DUT turns on and stays on when the gate is disconnected.
3. Open the circuit to the anode (with the gate connected to the cathode) and again reconnect the anode resistor. The DUT should now be off again.
4. For Triacs, repeat steps (2) and (3) with R2 supplied from a negative voltage.

If the device passes these tests, it is behaving properly and is probably functional. However, without applying full voltage or current, there is no way of knowing if it will meet all specifications.

You can replace the DC supply with a low voltage power transformer (say, 12 VAC). Use a scope to monitor the voltage across the DUT or R1. Then, when the gate is connected to R2, you should see the voltage across the DUT drop to nearly zero when it switches on partway through the positive cycle. This phase will be determined by the voltage and value of R2. It should remain off for the entire negative cycle (SCRs only) with the gate connected and remain off all the time with the gate connected to the cathode.

Testing Diacs and Sidacs

Diacs and Sidacs are thyristors without a gate terminal. They depend on the leakage current to switch them on once the voltage across the device exceeds their specified ratings. With an ohmmeter, they can be tested only for shorts. Resistance should be infinite in both directions.

However, you can test a diac or sidac with a resistor, variable power supply (you will need at least the rating of the device), and a DMM. Hook them in series as shown in Fig. 8 and monitor across the device. With care, your variable supply can be a Variac, a 1N4007 diode, and 1 µF, 200 V capacitor as shown. The 47,000-ohm resistor (R1) is used to limit the current:

CAUTION: This circuit is not isolated from the power line. I recommend using an isolation transformer between the variable voltage source (Variac) and the power line for safety. If the DUT is rated at more than about 180 volts, you will need to use a doubler and higher-voltage capacitor, but testing is otherwise similar.

As you increase the input, the voltage on the DUT will track it until the rated voltage, at which point it will drop abruptly to zero and stay there until the voltage is reduced below its holding current. Repeat with the opposite polarity.

With a scope, testing is even easier as you can use an AC supply directly (remove D1 and C1) and observe that the DUT will turn on at the proper voltage on both polarities of the AC waveform and stay on until the voltage crosses 0. But, again, use an isolation transformer for safety.

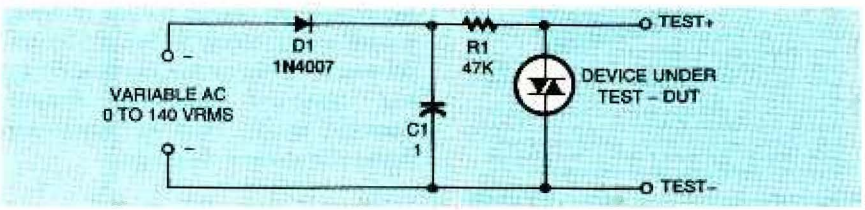

FIG. 8—A DIAC OR SIDAC is a thyristor without a gate. Use this circuit to test one.

Identifying Unknown Bipolar Transistors

The type (NPN or PNP) and lead arrangement of unmarked transistors can be determined using a multimeter and the back-to-back diode model discussed earlier. The collector and emitter can be identified based on the fact that the doping for the B-E junction is always much higher than for the B-C junction. Therefore, the forward voltage drop will be very slightly higher—this will show up as a couple of millivolts (sometimes more) difference on a DMM's diode-test scale or a slightly higher resistance on an analog VOM.

To determine the lead arrangement, label the pins on the unknown device 1, 2, and 3. Put the positive probe (as determined previously) of your multimeter on pin 1. Now, measure the resistance (VOM) or diode drop (DMM) to the other two pins. If the positive probe is on the base of a good NPN transistor, you should get low resistance readings or a low diode drop to the other two leads. The B-C resistance or diode drop will be just slightly lower than the B-E reading.

If one or both measurements to the other two pins is high, put the positive probe on pin 2 and try again. If still no cigar, try pin 3.

If this still doesn't work, you may have a PNP transistor—repeat with the negative probe as the common pin.

If none of the six combinations yields a pair of low readings—or if more than one combination results in a pair of low readings, your transistor is likely bad—or it is not a bipolar transistor at all!

As noted, some power transistors have built-in base resistors or damper diodes and will confuse these measurements. However, the lead arrangement of these types of transistors is usually self-evident (standard TO3, TOP3, or TO220 cases). There are also some tran-

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sistors with series base resistors that may prove confusing. These are relatively rare, however.

Testing MOSFETs

Verify that the gate has infinite resistance to both drain and source. There is one exception to that: FETs with protection circuitry may act like there is a Zener shunting the gate and source terminals (*i.e.*, diode drop for gate reverse bias, about 20-volts breakdown in forward bias).

Connect the gate to the source. The drain to source junction should act like a diode.

Forward bias the gate-source junction with about 5 volts. The drain-source junction in forward bias should measure very low resistance. In reverse bias, it will still act like a diode.

The usual failure mode you are likely to see with these devices is both a gate-source and drain-source short: In other words, everything connected together. Also, when handling these devices remember that MOSFETs are static sensitive!

Testing LEDs

Electrically, LEDs (and IR-emitting diodes, strictly speaking called IREDs) behave like ordinary diodes except that their forward voltage drop is higher. Typical values are IR: 1.2 volts; Red: 1.85 volts; Yellow: 2 volts; and Green: 2.15 volts. The new blue LEDs will be somewhat higher (perhaps 3 volts). These voltages are at reasonable forward current. Depending on the actual technology (*i.e.*, compounds like GaAsP, GaP, GaAsP/GaP, GaAlAs, etc.), actual voltages can vary quite a bit. For example, the forward voltage drop of red LEDs may range at least from 1.5 to 2.1 volts. Therefore, LED voltage drop is not a reliable test of color, though multiple samples of similar LEDs should be very close. Obviously, if the device is good, it will also be emitting light when driven in this way if the current is high enough.

You can test for shorts and opens with a multimeter (but it must be able to supply more than the forward voltage drop to show a non-open condition). However, an LED can be weak and still pass the electrical tests, so checking for output is still necessary. Therefore, even if these tests don't find a problem, drive the LED from a DC supply and appropriate current-limiting resistor and observe the output. For the IR types, you will need a suitable IR detector. See the document: "Notes on the Troubleshooting and Repair of Hand-Held Remote Controls" on my Web site (www.repairfaq.org) for a variety of options.

Testing Optoisolators and Photo-Interrupters

Both of these classes of components are basically similar: a light source (usually an IR LED) and photodetector together in a single package. The opto-isolator will be totally sealed with adequate separation between the two parts to provide the specified isolation voltage rating. The photo-interrupter (and similar devices) will provide a beam path that can be blocked or otherwise modified by external means.

For both types, the photodetector can be a photodiode, phototransistor, photothyristor, or another more complex device or circuit. Refer to an optoelectronics databook or the catalog of a large electronics distributor for specific pinouts and specifications.

Assuming a photodiode or photo-transistor type (most common), these can be tested for basic functionality pretty easily. Wire up the test circuit shown in Fig. 9. Depressing S1 should result in the output dropping from +5 volts to close to 0. For monitoring on a scope, drive the LED with a pulse generator and current-limiting resistor instead of S1. With a photo-interrupter type, blocking or adding a reflector to the optical path (as appropriate) should result in similar behavior.

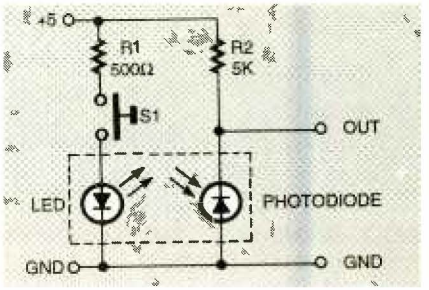

FIG. 9—A SIMPLE CIRCUIT for testing opto-isolators.

Testing Thermistors

There are two types of thermistors: Positive Temperature Coefficient (PTC) types have a resistance that increases with increasing temperature. Negative Temperature Coefficient (NTC) types have a resistance that decreases with increasing temperature.

For a small thermistor, put an ohmmeter on it and heat the device under test with a blow dryer, heat gun, or the tip of a soldering iron—the resistance should change smoothly (up or down depending on whether it is PTC or NTC type). If the resistance changes erratically or goes to infinity or zero, the device is bad. However, you will need specifications, temperature measuring sensors, etc., to really determine if it is operating correctly.

Wrap-Up

Next time, we will continue our discussion of semiconductor testing with additional service-related information and some very simple curve tracer and in-circuit tester schematics. In a future column, we'll discuss the specific problem of testing the laser diodes found in CD and DVD equipment and laser printers. Until then, check out my Web site: www.repairfaq.org. I welcome comments (via e-mail please at sam@stdavids.picker.com) of all types and will reply promptly to requests for information. See you next time! EN

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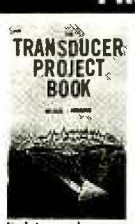

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BY SAM GOLDWASSER
SERVICE EDITOR

More on Semiconductor Testing, DVD Notes, and More

THIS MONTH WE'LL COMPLETE OUR DISCUSSION OF SOLID-STATE DEVICE TESTING ALONG WITH SOME VERY SIMPLE CIRCUITS THAT CAN BE PUT TOGETHER IN ABOUT 10 MINUTES TO DISPLAY THE CHARACTERISTICS OF TWO-TERMINAL DEVICES ON an oscilloscope. We'll also inaugurate an occasional series of short topics on other aspects of repair or follow-ups to previous articles. This time: What about DVD player or DVD-ROM drive servicing?

Diode and Rectifier Speeds

When the polarity reverses on a diode, it takes finite time for the charge carriers to be cleared from the area of the junction. During this time, reverse current flows. For high-frequency applications—*i.e.*, switching power supplies, horizontal deflection circuits, etc.—a normal diode would act more like a short circuit and result in poor performance or even burn out.

There are a variety of alternatives: fast-, super-fast-, ultra-fast- (and so forth) recovery diodes, Schottky diodes, and others that must be used in high-frequency signal, switching, and power-supply circuits. Thus, if you find a bad diode in a piece of electronic equipment, don t assume it is just an ordinary diode because the case looks the same. Replacing a fast-recovery diode with a 1N4007 will very likely just result in more confusion. A proper device must be used even for testing. In most cases, a faster part can be substituted without problems. However, there are occasional situations where the specific characteristics of a slow part (a reverse pulse due to its long recovery time or high capacitance) are needed for the circuit to operate properly!

Horizontal Output Transistor Pinouts

The next discussion might go in the "general trivial department," but it might also come in handy if you haven't been playing with horizontal output transistors (HOTs) all your life!

You will nearly always find one of two types of HOTs in TVs and monitors, and those are shown in Fig. 1. Some other transistor types use the same pinout (TO3—see Fig 1A—for metal can, TOP3 and TO220—see Fig. 1B—for plastic tab), but not all. However, for horizontal output transistors, those pinouts should be valid.

Note that HOTs with a built-in damper diode may read around 50 ohms between B and E (near 0 on the diode test range)—this is normal as long as the resistance is not really low (under 10 ohms).

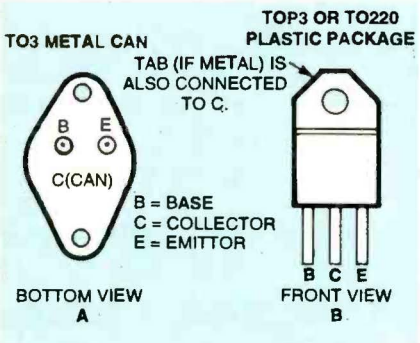

FIG. 1—HOT PACKAGES: a TO3 metal can is shown in A, and a TO220 plastic package is in B.

Difference Between Normal and "R"-Marked Parts

Electrically, normal and "R"-marked parts are exactly the same. The R stands for "reverse." The "R" pinout is a mirror image of the normal one. This makes layout of high-frequency pairs easier because traces do not have to cross over one another. However, it can also bite you if you are unaware of what the marking means!

Testing MOVs

Metal-oxide varistors (MOVs) are used mostly for surge suppression in power strips and the front-ends of the power supplies of TVs, VCRs, and other consumer electronic equipment. They are those brightly colored things that look like Epoxy-dipped capacitors. At least, that's what they look like when new. A common failure mode is for the MOV to be totally obliterated by a surge or from old age. In such cases, testing is not needed!

MOVs are supposed to be located beyond the line fuse (though possibly not always). In this case, where the line fuse blows but there is no visible damage to the MOV(s), the simplest test may be to just temporarily remove the MOV(s) and see if your problem goes away.

A multimeter can be used to test for leakage (there should be none), but the best option is to remove the device. Since the proper functioning of the equipment doesn't depend on any MOVs (in 99.9999 percent of the cases—the exception being where the MOV is used as a high-voltage triggering device or something like that rather than a surge suppressor), remove the MOV(s), test the equipment, and then just replace the MOV(s) if in doubt.

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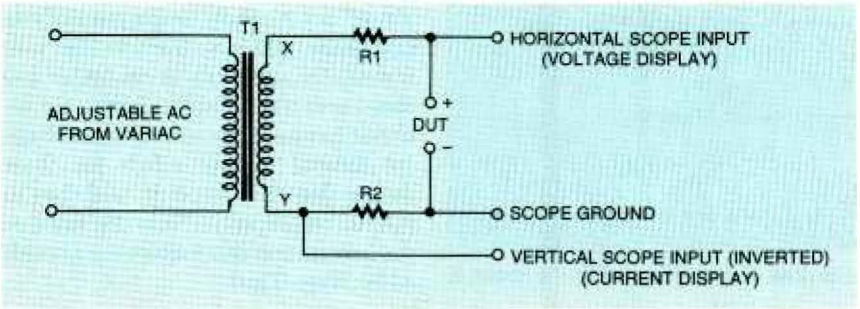

FIG. 2—THIS "QUICK AND DIRTY CURVE TRACER" can tell you a lot about the value and health of a wide variety of components. It is used with an oscilloscope.

Introduction to Curve Tracers

A curve tracer is a piece of test equipment or an add-on to an oscilloscope that provides a graphical display of the V-I (or other parameters) of an electronic component. The design of a curve tracer is simple in principle; let's look at one designed for testing bipolar transistors.

For the horizontal (collector supply) you need a variable-ramp generator. If your scope has a sweep output, then you can derive it from that—if you are not interested in frequency response, an audio amplifier may be adequate with a volume control to adjust the amplitude.

For the base drive you need a programmable current source capable of putting out a series of constant currents; for example, a counter driving a D/A set up for a current-output mode. Use the trigger output or sweep output of the scope to increment the counter so that it sequences through a set of say 10 current settings. Then, you can jazz it up with microprocessor-controlled on-screen display.

Curve tracers can be big expensive things or little add-ons to regular scopes. If you want to build your own, kits are available from sources such as Gootee Systems (http://www.fullnet.com/u/tomg/). I have no idea how good their unit is, but you can get more information on their Web page. Also, **Popular Electronics**, May 1999, has complete plans for a "Semiconductor Tester" that can handle NPN and PNP bipolar transistors, JFETs and MOSFETs, all sorts of diodes including Zeners, and a variety of other devices. This is basically a curve tracer adapter for an oscilloscope. With a little ingenuity, it can be enhanced to test virtually all the semiconductors discussed in last month's Service Clinic (and more).

Therefore, if you want a sophisticated piece of test equipment, one of these would be suitable. Or, get yourself a used Tektronix 575 curve tracer. It will do just about everything you could possibly want (including the testing of vacuum tubes with the addition of a bit of external circuitry.)

However, to just test two terminal devices—or to just get a feel for device characteristics, there are much simpler, cheaper, alternatives.

Quick and Dirty Curve Tracer

I built the circuit shown in Fig. 2 in about 10 minutes. With minor modifications, it is capable of displaying V-I curves for diodes, Zeners, transistors, thyristors, resistors, capacitors, inductors, etc.

I used a 12 VAC transformer for T1 just because it was handy. You can use anything you like as long as you understand the safety implications of higher voltages and make sure the components you use can withstand the power that might be dissipated in them if the Device Under Test (DUT) is a dead short. In addition, it is bad form to blow out the DUT while testing it! A signal generator driving a small audio transformer could also be used if it is desired

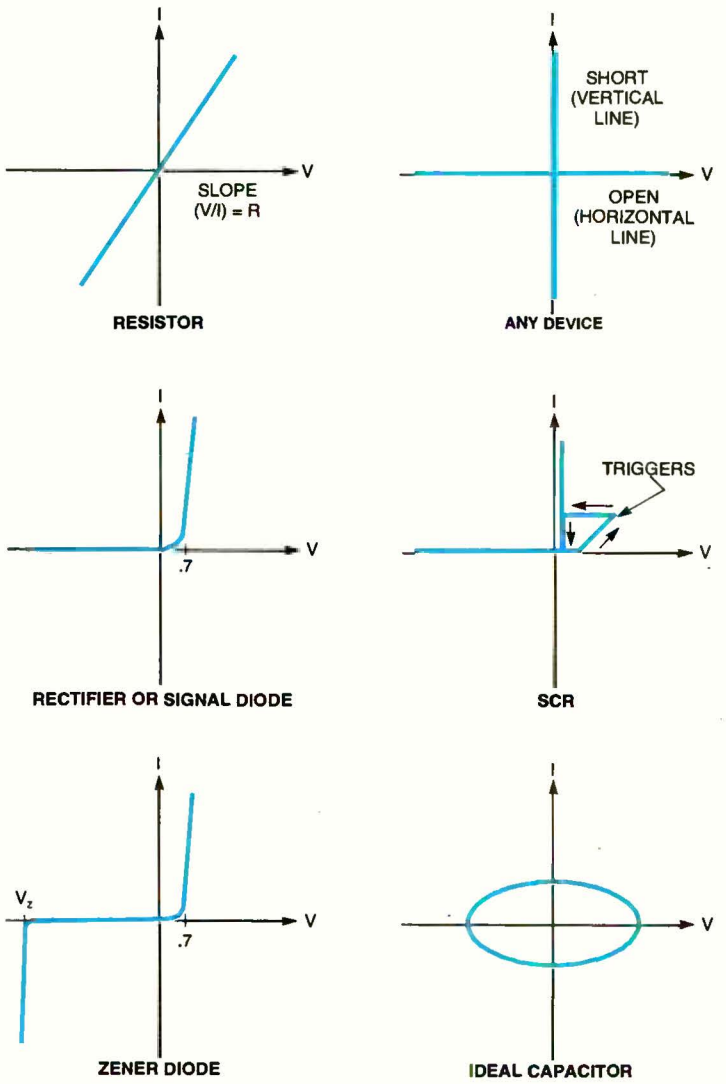

FIG. 3—THESE WAVEFORMS are what you'll see on your oscilloscope when testing a variety of components.

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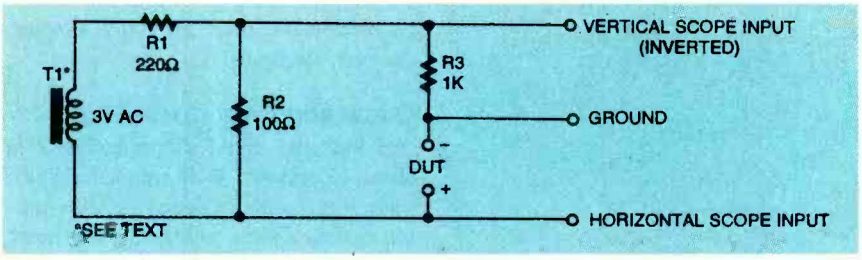

FIG. 4—THIS CIRCUIT IS ALL you need to test devices while they are still in the circuit. It is from an article that appeared in 1975.

to test components at frequencies other than 60 (or 50) Hz.

CAUTION: Turn down the intensity of the scope so the spot is just barely visible so that when there is no input, you don't end up drilling a hole in the face of the CRT! Here are some other circuit notes:

R1: Current limiting and phase shift control. I used 500 ohms, which works well for small signal semiconductors and capacitors of around 1 μF.

R2: Current sense. I used 10 ohms and put the scope on the one of the.1, .2, or 0.5 V/cm ranges.

T1: Small power transformer. I used the 12 VAC wall wart from an obsolete modem. This will supply a voltage of up to about 17 V peak to your DUT. For higher power or higher voltage devices, substitute a suitable larger transformer.

Modify these (selector switches might be nice) for your needs. A Variac provides a convenient method of adjusting the voltage applied to the DUT.

So what will you see on the scope? Some typical curves are shown in Fig. 3.

• Zener diodes—the result will be exactly like the picture in your textbook. Try this with a 5 or 6 V Zener to confirm that your rig is working.

• Resistors—the display should be a straight diagonal line. You should be able to compute their value from the ratio of V to I. If the device is open or shorted, the display will be either a horizontal or vertical line, respectively.

• Capacitors—you should see the phase shift between voltage and current resulting in an ellipse (though you will probably have to adjust the scale factors to obtain a usable display with typical capacitor values).

• Bipolar transistors—a source of (DC) base current is needed. You can be fancy or simple. For a simple source, I used a variable 0 to 15 V power supply and a current limiting resistor. Since we know that the voltage drop across the B-E junction is fairly constant at around 0.7 V (for silicon), the output of the supply can be calibrated in terms of base current.

TABLE 1—SCOPE DISPLAY

Resistors:	
Open	Horizontal line
10 K	10 degree
1 K	45 degree
0	Vertical line.
Capacitors:	
1 mF	Shallow ellipse
2.6 mF	Circle
50. mF	Narrow vertical.
Transformers:	
Ellipse depending on impedance	
Diodes (Germanium):	
Right angle display	
Diodes (Silicon):	
Right angle one side longer (any leakage showing less sharp angle)	
Transistors:	
Test as two diodes (B to E and B to C)	
Integrated Circuits:	
Input for gates and counters show a certain signature display	
Outputs display a different signature	
A short will show a vertical line	
An open will show a horizontal line	

• SCRs—connect a suitable resistor in series with a diode or two (or a diac) between the gate and the DUT positive terminal (so gate current is included in the V-I curve). When the threshold current is exceeded, the device should turn on and remain on until the zero crossing. With the reverse polarity, the device should remain off. For Triacs, use diodes in parallel in both directions, or a diac. A Triac should trigger on both polarities of the AC waveform.

In-Circuit Tester

In the August 1975 issue of *Popular Electronics*, author Lou Garner wrote a story called "A Simple On-Board Tester" about a fairly simple piece of test equipment, which is shown in Fig. 4. It is along the same lines as the "quick and dirty curve tracer," but is suitable for in-circuit testing as the current and voltage are limited to safe values for most devices (less than 1-volt AC and than 1-mA AC respectively). Note that some of the information that follows was provided by Wern Thiel.

CAUTION: Use at your own risk. I cannot absolutely guarantee that there won't be certain devices in use today that didn't exist in 1975 and that might be unhappy with this approach.

The device can be used with any type of oscilloscope and consists of a 6-volt filament transformer, three 1/4-watt resistors, and two test probes. Half of the filament voltage is applied to a voltage divider consisting of 220-and 100-ohm resistors, yielding 1-volt AC on top of the 1000-ohm resistor. This voltage can be applied to any component or combination of components across which the test leads are placed. The current is limited to one milliampere by the 1000-ohm resistor.

The voltage across the probes is connected to the horizontal input of a scope while the voltage across the 1000-ohm resistor as a result of the current through it is connected to the vertical input. What we see on the scope is a voltage across a component under test versus the current through the component and is summarized in Table 1.

In-circuit testing is done with **no** power applied to the equipment under test. With some experience one should be able to test components in and out of circuit and troubleshoot without danger of damage to components.

Testing Vacuum Tubes or FETs

A transistor curve tracer can be easily adapted to test vacuum tubes if it has an adequate voltage range for the collector (now plate) drive and independent control of base and collector polarity. All that is needed is to add a separate transformer to power the tube s filament(s) and a resistor to convert base current to voltage. For FETs, just leave off the transformer. Michael Covington (author of the Q&A column in **Electronics Now**) suggests the following:

"Get an old Tektronix 575 (mine cost $25 at a hamfest). That is a transistor curve tracer that goes back to the 1950s and goes up to 200 volts. It doesn t have FET settings, but you can control the "base" and "collector" polarity independently. So what

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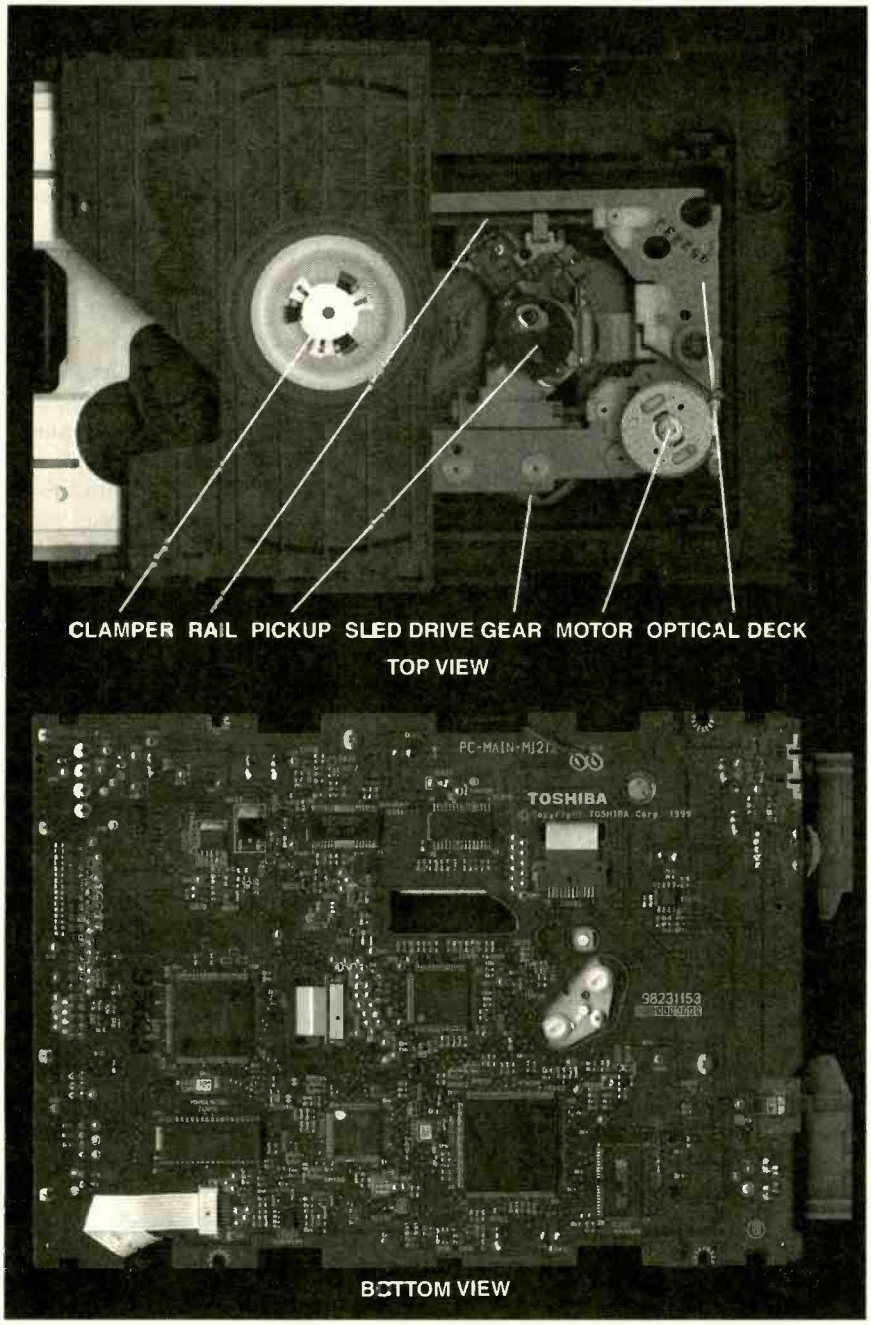

FIG. 5—INSIDE A TYPICAL DVD-ROM drive. Mechanically, they do not look very different from CD-ROM drives, though the electronics seem more complex.

you do is put a 1000-ohm resistor from "base" to ground, so that you can read milliamps as volts. Then put a positive-going voltage on the "collector" and a negative-going current into the "base." For tubes, emitter, collector, and base are cathode, plate, and grid, respectively. Naturally you also need a filament supply; I use a lab-type DC supply because it's handy and can't introduce hum. I also test FETs that way (without the filament supply, of course). Then, emitter, collector, and base become source, drain, and gate respectively."

That's it for semiconductors for now—in a future column we will delve into the problems of testing and powering the types of laser diodes found in CD and DVD players, laser printers, and other laser-based consumer electronics equipment.

DVD Player and DVD-ROM Drive Servicing

We covered CD-player operation, troubleshooting, and repair, in a complete series of Service Clinic columns a while ago. Since then, DVD technology has really taken off and (if you believe the marketing hype) is about to replace CDs totally. Realistically, this won't happen for some time. In any case, DVD players and DVD-ROM drives are *supposed* to accept CDs, CD-Rs, and CD-RWs, so no need to panic just yet. But availability of new CD-based devices will disappear because the cost to manufacture a DVD player or drive isn't much more than that of a similar CD unit, so manufacturers will want to close down their old production lines and concentrate on DVDs only.

Photos of a DVD-ROM drive are shown in Fig. 5. That unit, a Toshiba SD-M1212, is typical of the units shipped with bundled PCs (I believe this was from a Dell Dimension 450 MHz Pentium II system). The most notable feature of the optical deck used here is that it really is very similar in appearance to those used with late model CD players or CD-ROM drives. In fact, without the DVD logo or other distinguishing markings, it could just as well have been a CD-ROM drive (of course, we know that what's inside is quite different at least in the details). I wasn't willing to go any deeper since this is still a working unit so there could be internal differences. An update will be forthcoming when I get my hands on a broken one!

One thing that is obvious is the amount of circuitry compared to a late model high-speed CD-ROM whose PCB typically occupies less than ⅓rd of the available area. I don't know how much of the added circuitry is due to it just being newer technology that hasn't been as highly integrated yet as opposed to the additional complexity required for DVD decoding and support for CD audio and data formats as well.

In any case, eventually all things break, and DVD equipment will be no exception. Fortunately for us, the similarities between CD and DVD technology are much more significant than the differences. The inside of a DVD player looks pretty much the same as the inside of a CD player and, for the most part, the same problems are likely to occur. Here are some things to look out for:

DVD discs (if you haven't seen one yet) look virtually identical to CDs. They are the same size and thickness with the same large center hole and will fit perfectly well into a CD player or CD-ROM drive—but of course it won't do much there. Despite the tracks and

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TABLE 2—CD vs. DVD

Parameter	Compact Disc/CD-R	Digital Versatile Disc
Disc diameter	20 mm	120 mm
Disc thickness	1.2 mm	1.2 mm
Disc structure	Single substrate	Two bonded 0.6 mm substrates
Laser wavelength	780 nm	650 to 635 nm
Numerical aperture	0.45	0.60
Track pitch	1.6 mm	0.74 mm
Minimum pit/land length	0.83 mm	0.4 mm
1× speed (CLV)	1.2 m/sec	4.0 m/sec
Number of data layers	One	One or two
Number of sides	One	One or two
Data capacity	~680 MB	4.7 GB (one layer) 8.5 GB (two layer) 17 GB (two layer, two sides)
User data rate (13)	153.6 K/sec (mode 1)	1108 K/sec (mode 1) 176.4 K/sec (mode 2)

pits being closer together, the rainbow/diffraction effects are about the same so a casual glance isn't enough to tell them apart, but there is always that DVD logo! However, the information layer is precisely in the center of a sandwich of polycarbonate (each half 0.6 mm thick). The DVD standard supports a double-sided DVD. If a DVD is two sided (many aren t), that of course leaves virtually no room for the label!

A comparison of major CD and DVD characteristics is shown in Table 2. Here are some additional notes:

• The reduced track pitch and pit length made possible by the shorter wavelength and advances in optical readout technology accounts for the almost 8-fold increase in data storage capacity on a single layer.

• The laser in a DVD-based device is a very visible red (a wavelength around 650 nm compared to the nearly invisible IR 780 nm laser used for CDs). This is about the same wavelength as used in newer red laser pointers. It is still low power (1 mW or less at the objective lens) but the laser will appear very bright when it is powered and working correctly. As far as hazards to vision, the same recommendations apply—don't look into the beam directly, but viewing from an oblique angle at 12 inches or more from the objective lens should be safe. The eye's aversion reflex will prevent damage in any case—you will blink or turn away from the bright light.

CAUTION: Some (probably older) DVD equipment may also have a standard CD pickup to be able to read CDs. For these, obviously, all the IR laser precautions apply.

• It should be easier to determine if the laser is bad by brightness alone though a laser power meter, and the manufacturer specifications will still be needed in marginal cases.

• As a result of the march of technology, the optical pickup is likely to be of simpler design than that in older CD-based devices with even fewer or no adjustments possible. However, there could be additional complexity due to the need to handle DVDs and CDs in the same equipment. The use of combined laser diodes and photodetector arrays is likely to be quite common if not pervasive.

• The same basic functions need to be performed by the front-end electronics, including amplification of the photodetector array output, and focus, tracking, and spindle servos. Much of this is likely to be done inside large chips with no service adjustments possible.

• More functions will be incorporated into fewer surface-mount chips. Fortunately, failures of the large-scale integrated circuits themselves are not nearly as common as simple mechanical problems. We'd better hope so in any case as troubleshooting of things like an MPEG decoder is way beyond what could be done without a complete service manual, sophisticated test equipment, and probably a whole lot more!

• More plastic and less metal is likely to be used, making the unit lighter, flimsier, and less likely to be serviceable at all.

So, the bad news is that if something breaks inside a large chip, accept defeat and send the unit in for service. The good news is that most problems will still be mechanical—dirt, dust, gummed up grease, bad motors, abuse. From our experience with CD repair, we should be well equipped to deal with these!

Hopefully, manufacturers have learned from their experience with CDs to make a more reliable robust product, but that may be wishful thinking where the bottom line is involved. It's still too early to tell.

For more information on DVD technology, check out the following sites:

• DVD FAQ: www.videodiscovery.com/vdyweb/dvd/dvdfaq.html
• Digital Video Disc (DVD) Technolgy: www.c-cube.com/technology/dvd.html
• Philips Optical Storage: www.km.philips.com/laseroptics/
• DVD Central @ etown.com: The Home Electronics Guide: http://community.etown.com/dvd/

Wrap Up

That's it for now. Next time we start on the exciting world of VCR repair. Until then, check out my Web site, www.repairfaq.org. I welcome comments (via e-mail please) of all types and will reply promptly to requests for information. Sorry, I really cannot answer postal mail, but might include a response in a future column (if interest warrants). See you next time! EN

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